Direction-sensitive dark matter search with a gaseous micro time projection chamber(Digest_要約)

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Non-baryonic dark matter is widely believed to account for a large fraction of the mass in the universe by a lot of observation of universe[1]. Weakly Interacting Massive Particle (WIMP) is the leading candidate of the dark matter[2]. Direct search experiments pursue for the signal of WIMP-nucleus elastic scatterings, where WIMPs in the halo of our galaxy are expected to be detected on the Earth[3]. Direct search experiments can provide the robust evidence of the existence of the halo dark matter. Since the shape of the expected energy spectrum is exponential-like, the decrease of threshold energy is important to get enough signals. A relevant energy region is considered to be below 100 keV. Expected event rate is very low due toa small cross section of a WIMP interacting with an ordinal matter. Therefore, these experiments are needed to be performed in underground facilities.

Many direct search experiment of dark matter have been performed so far. Although some experiments have reported a positive result, no experiments have reached widely agreed discovery. In order to obtain a robust evidence of the dark matter, more reliable signal is needed. A most convincing signal of the dark matter would be seen in the directional distribution of the recoil nucleus. Since the Cygnus constellation is seen in the forward direction of the Solar system's motion, dark matters would seem to come from the Cygnus direction like "WIMP-wind". Since the Cygnus direction is varying per hour and per day, the systematic error due to the daily and seasonal environmental variation will be canceled. A gaseous detector with a good position resolution is required for the direction-sensitive search in order to detect a shorter track than 1 mm in atmospheric pressure gas.

We have developed a direction-sensitive dark matter detector, NEWAGE-0.3b' to improve the sensitivity by one order of magnitude from previous measurement performed by NEWAGE-0.3a[4]. NEWAGE-0.3b' consists of a micro time projection chamber (μ-TPC), its electronics system, and the gas circulation system with cooled charcoal. μ-TPC consists of a micro pixel chamber (μ-PIC) which is a two-dimensional fine-pitch imaging device, a gas electron multiplier (GEM), and $30 \times 30 \times 41\,\mathrm{cm}^3$ of detection volume filled with 0.1 atm of CF_4 gas. NEWAGE-0.3b' was designed to have a twice larger target volume with low background material, a lowered threshold, and an improved data acquisition system. By a detector study prior to the dark matter search experiment, the energy threshold with an angular resolution of 40° was confirmed to be lowered from 100 keV to 50 keV[5].

A direction-sensitive dark matter search in Kamioka underground laboratory with NEWAGE-0.3b' was performed from 2013/07/17 to 2013/11/12. Compared to the previous measurement with NEWAGE-0.3a, obtained background level was reduced by $\sim 1/10$ in the energy range of $100 - 400$ keV. Obtained directional distribution was roughly isotropic, which means that the background is still dominant. With an exposure of 0.327 kg · days, a new 90% C.L. direction-sensitive SD cross section limit 557 pb for WIMP mass of 200 GeV/c^2 was obtained. This result is improved by a factor of ~ 10 from previous measurement, and marks the best direction-sensitive limit.

The identification of the background soruce is very important to improve the low background detector. The background sources of the high energy events were clearly divided into radon gas and μ-PIC-side. The amount of the radon gas was evaluated by fitting the radon peak. Obtained anglar distribution of the μ-PIC-side events was concentrated to upper direction. From the simulation result, α particles from the polyimide in the μ-PIC, which pass thorough the GEM holes, was found to be the main component of μ-PIC-side background, and the amount of U/Th-chain in the polyimide was evaluated. Measured low energy background was explained by the partialy energy deposit events of high energy background events. The estimated external backgrounds (cosmic-ray muons, environmental neutrons, and environmental gamma-rays) were not dominant. These result shows the polyimide of the μ-PIC is the dominant background source even in low energy range, and must be removed.

If a new low-background μ-PIC is developed, the background level will be limited by environmental gamma-rays and it will be reduced by constructing a lead shield. The expected limit with the above improvements will reach to the DAMA region[6]. Further sensitivity will be achieved by recognizing the head/tail of the track, improving angular resolution, and using large-size detectors with long-term operation, and then a direction-sensitive dark matter search of DAMA region will start.

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